REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	AUG 1996	FINAL 10/01/96--09/30/97

4. TITLE AND SUBTITLE FY97 AERO PROPULSION & POWER TECHNOLOGY AREA PLAN

5. FUNDING NUMBERS
C
PE
PR 9993
TA 00
WU 00

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AEROPROPULSION AND POWER DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7251

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7251

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

WL-TR-97-2000

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

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12b. DISTRIBUTION CODE

13. AB

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14. SUB

OF PAGES 40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

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Prescribed by ANSI Std. Z39-18
298-102

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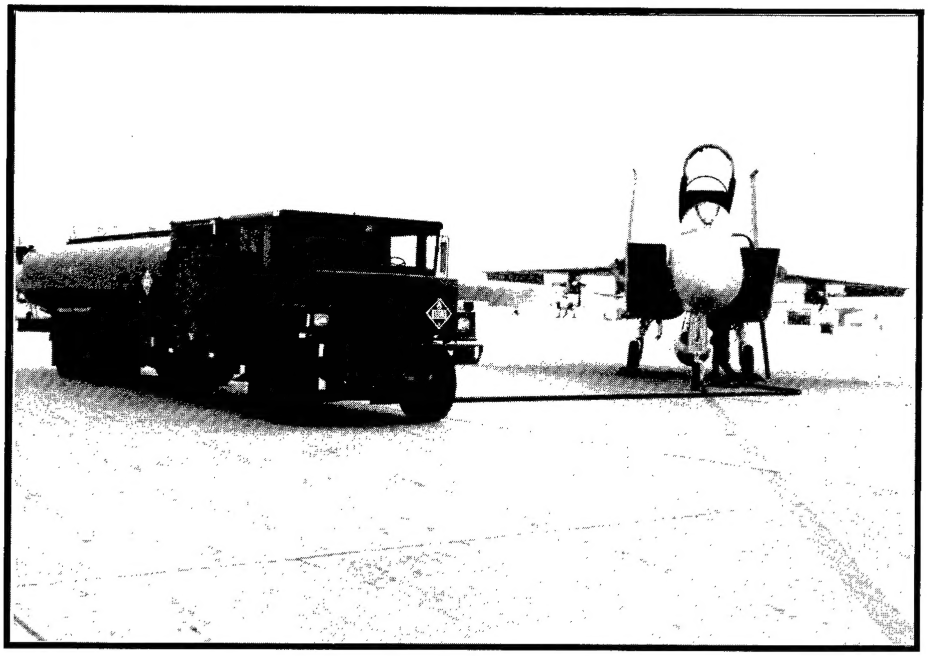
FY97
Aero Propulsion & Power Technology Area Plan



Headquarters Air Force Materiel Command
Directorate of Science & Technology
Wright-Patterson AFB OH

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Note

This Technology Area Plan (TAP) is a planning document for the FY97-03 S&T program and is based on the President's FY97 Budget Request. It does not reflect the FY97 Congressional appropriations and FY97-03 budget actions, that may impact the S&T budget in selected TAPs. You should consult WL/POM, (513) 255-2622 for specific impacts that the FY97 appropriation may have had with regard to the contents of this particular TAP. This document is current as of 1 August 1996.

Internet access

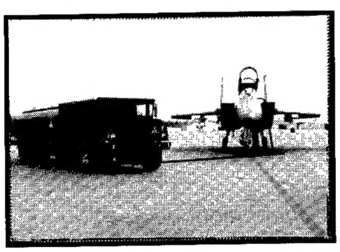
An electronic copy of the most recent Aero Propulsion and Power TAP and other Air Force TAPs are now available on the world wide web (letters are case sensitive):

http://stbbs.wpafb.af.mil/STBBS/info/taps/fy96/propulsn/final.doc

Additional information concerning this technology area is available on the Aero Propulsion and Power home page:

http://podev.appl.wpafb.af.mil:8001/home.html

On the cover



The F-15 pictured is being refueled with an improved jet fuel (JP-8+100) at Otis Air National Guard Base, MA. This newly developed fuel is reducing engine and aircraft fuel system maintenance costs. Recent operational tests at another guard unit demonstrated a cost avoidance of over $850,000 per year. JP-8+100 is conventional jet fuel (JP-8) with a "fuel injector cleaner" (additive) that reduces engine and aircraft fuel system fouling and coking – at virtually no additional cost. It also reduces smoke and soot in older engines. The JP-8 specification, MIL-T-83133D, was recently amended to allow limited use of the additive with approval for fleet-wide use to follow.

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Visions & Opportunities

The Aero Propulsion and Power technology area is responsible for developing airbreathing propulsion and power technology for Air Force use, with a heritage reaching back to 1917. We are a proud part of Wright Laboratory, Aeronautical Systems Center, Air Force Materiel Command located at Wright-Patterson Air Force Base near Dayton, Ohio.

Despite many advances since the dawn of the jet age, the potential for turbopropulsion has been only partially realized. By around the turn of the century, we expect this potential in terms of propulsion capability to be doubled relative to a 1988 technology baseline. This will be achieved through the Integrated High Performance Turbine Engine Technology (IHPTET) program.

Started within DoD – with support from the Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA), and industry – this effort focuses the nation's research and development (R&D) resources to provide dramatic increases in engine affordability, durability, and performance. IHPTET is structured to meet emerging aircraft and missile turbopropulsion needs – current and future, military and commercial. IHPTET enables:

- Upgraded and derivative engines – to enhance durability, performance, life, and survivability – that will lower cost of ownership and increase force effectiveness.
- New engines – with major emphasis on acquisition and maintenance cost reduction – that leads to revolutionary weapon system capabilities.
- Dual-use technologies – transferred from military applications – to improve commercial, industrial, and marine turbine engines.

As one looks far into the future (2025), the turbine engine continues to play a critical role not only in our national defense, but in our U.S. national economy as well. Turbine engines will continue to revolutionize both military and commercial aircraft, will grow in usage for tanks, ships, and recreational vehicles and will become a vital source of electrical power generation throughout the world. The turbine engine will, in one way or another, enhance the lives of nearly every person on the planet.

New high speed airbreathing propulsion efforts are focused on the Air Force vision "Global Reach - Global Power." In support of this vision, advanced ramjet, scramjet, and combined cycle engines will provide the capability for sustained flight up to Mach 8 using conventional hydrocarbon fuels. Some examples of revolutionary capabilities achievable through high Mach airbreathing propulsion include:

- High speed air-to-ground missiles that rapidly attack time critical and hardened or deeply buried targets from long and inherently safe standoff ranges.
- Light weight attack weapons that lead to force multiplication through increased range, loadout, and mission flexibility.
- Air-to-air missiles with significantly increased launch and no-escape zones, providing air superiority well into the next century.
- Global, fast reaction strike and reconnaissance aircraft that can operate from existing airfields within the United States, using conventional fuels.
- Lower stage propulsion for future military and commercial launch vehicles – enabling increased payloads and hence, more affordable access to space.

Fuels and lubrication will continue to be the "life blood" of gas turbines. Circulation of these fluids for aircraft thermal management will maintain the health and integrity of all systems. Future capabilities will include:

- A single, affordable high temperature capable jet fuel that eliminates fuel system deposits and related maintenance. This fuel will be applicable to both air and ground vehicles operating throughout all engine cycle temperatures and vehicle speeds.
- Improved combustors that operate at high temperatures while reducing fuel consumption and pollution.
- Lubrication systems with fewer parts that weigh 50% less than existing systems. Included will be alternative nonlubricated mechanical components – such as magnetic bearings.

An essential feature of today's and tomorrow's systems is power. Our vision in this area is found in the More Electric Aircraft (MEA). This initiative is focusing technology developments of the services, NASA, and industry for the entire range of aircraft power components. Already underway, these developments will provide substantial benefits to both the Air Force and the nation:

- Power-by-wire, via the More Electric Aircraft approach, that allows substantial reduction in aerospace ground support equipment and more than doubles reliability for aircraft power systems by eliminating existing on-board hydraulic, pneumatic, and mechanical power subsystems.
- Use of MEA technologies that offer about an additional 10% sortie rate for a typical wing of F-16s over a 30-day war.
- MEA technologies that transition to the operational fleet to extend the life of the aircraft and to reap improved reliability, maintainability, and supportability (RM&S).

This look towards the future gives insight to the breadth of work and vision of the Aero Propulsion and Power technology area. The program benefits all aspects of Air Force operations by providing balanced improvements in affordability, performance, and supportability. The technologies will continue to be adopted by the other services and the civilian sector, as they have been for decades.

This plan has been reviewed by all Air Force laboratory commanders/directors and reflects integrated Air Force technology planning. I request Air Force Acquisition Executive approval of the plan.

RICHARD W. DAVIS, Colonel, USAF
Commander
Wright Laboratory

RICHARD R. PAUL
Major General, USAF
Technology Executive Officer

Contents

Introduction

Background

Aero Propulsion and Power, highlighted in Figure 1.1, is an integral part of the Air Force (AF) Science and Technology (S&T) program. It is also a key component of the Air Platform technology area described in the Department of Defense (DoD) Technology Plan (DTAP) that describes the total DoD S&T effort. This DoD plan – as well as the Air Force program – is responsive to the S&T strategy issued by the Director of Defense Research and Engineering (DDR&E) and is in partnership with other government agencies, industry, and academia.

We play a major role in developing and executing Wright Laboratory's (WL) investment strategy that is based on guidance received from the Technology Executive Officer. This strategy complies with DoD guidance as reflected in the Basic Research Plan and the DTAP. It maintains a balanced S&T program in terms of basic research, exploratory development, and advanced development. It is responsive to documented "warfighter" needs, the changing defense budget, and an increasing need to develop more affordable, durable weapon systems, while avoiding costly R&D duplication. This strategy assumes buying fewer new systems and relying more on system upgrades using proven technological innovations.

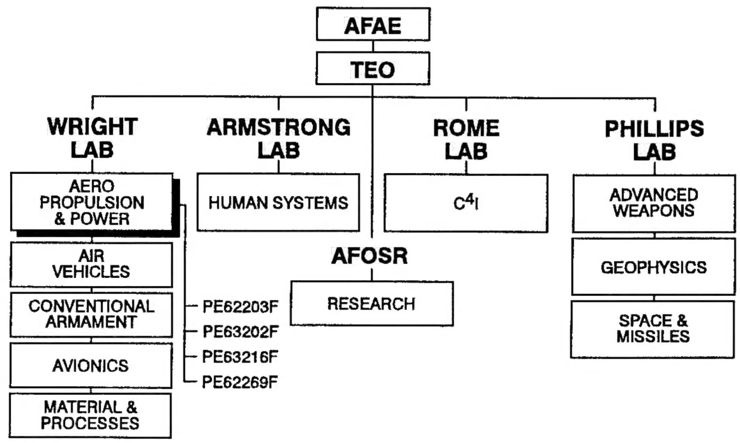

Figure 1.1 Air Force S&T program structure

Specific programmatic plans for guiding our investments in research and technologies are:

- Maintain the pace, meet the milestones, and achieve the technology goals established by DDR&E as part of a national S&T investment strategy.
- Address key recommendations of the Scientific Advisory Boards' (SABs') New World Vistas (NWV) – a study describing essential capabilities needed by the Air Force of the 21st century.
- Address recommendations of other evolving long-range planning initiatives (e.g., Air Force 2025 – a study directed by the Chief of Staff of the Air Force to envision capabilities in air, space, and information power in the far future).
- Continue the momentum in applicable Air Force special emphasis/focus areas – for our technology area this applies to aging aircraft and high cycle fatigue.

Augmented and redirected funds are being identified to provide focused support to NWV, AF 2025, and special emphasis/focus areas. This is in partnership between the Air Force Office of Scientific Research (AFOSR) and the laboratories under the Third Millennium Initiative (TMI). This initiative is providing additional dollars to Air Force labs to enhance needed research. Targeted is significant S&T funds through the current planning cycle (FY97 through FY03).

Our technology area – involving the research and development of turbine engines, fuels and lubricants, high speed propulsion, and aircraft power – is responsive to this S&T guidance.

Compliance is assured through frequent reviews with DDR&E, Air Force Materiel Command (AFMC), SAB panels, and AFOSR.

Aero propulsion and power technologies are common to all services. Most Army, Navy, and commercial engines are derivatives of Air Force power plants that we helped to conceive, develop, and/or demonstrate. All services use our developed fuels and lubricants. These numerous applications are primarily due to proven, practical technologies being available and affordable when needed by the users.

Joint programs are the most common business practice within this technology area. Examples include the Integrated High Performance Turbine Engine Technology (IHPTET) program, the More Electric Aircraft (MEA) initiative, and the evolving Wright Laboratory Hypersonic Technology (HyTech) program. All of these efforts successfully leverage precious resources to include people, facilities, and R&D dollars.

We make every attempt to be responsive to relevant user deficiencies/needs. These are identified via the Air Force Modernization Planning Process (AFMPP) and are articulated through the Technology Master Process (TMP) being implemented by AFMC. The TMP provides a comprehensive process for technology development, transition, and application/insertion having strong user endorsement. The TMP has allowed us to tie our technologies more closely with the needs of the warfighters.

The process is mature after two years of implementation. The major commands have developed Mission Area Plans (MAPs) that document user mission "capability deficiencies." The Technology Planning Integrated Product Teams (TPIPTs) – led by the product centers with participation from laboratories, test centers, logistics centers, and major commands – continuously examine these deficiencies, roadmap system level solutions, and identify the technology needs associated with the postulated system solutions or functions.

The FY96 AFMPP – ASC Concept Call – Deficiency Data report provides a consolidated list of these deficiencies prepared by the Aeronautical Systems Center (ASC) for air vehicles and weapons. This document is available to the DoD and U.S. DoD contractors. In general terms, aero propulsion and power addresses customer needs to enhance engine performance, reduce signatures, improve range, increase durability, lower cost, reduced hazardous materials, reduce aircraft support equipment, and provide missile propulsion capabilities to engage targets at extended range and kill time critical targets. More specific details are discussed in the thrust chapters that follow.

Accomplishments have been plentiful. During the past year, we met IHPTET's Phase I goals for turboprop/turboshaft engines. These include increase in horsepower-to-weight ratio and reduction in fuel burn. IHPTET Phase I is now complete and Phase II is well underway with new cost reduction goals. We continue to work with our users to speed the transition of turbine cooling and exhaust nozzle technologies into current and future engine families. Finally, we continue to push the development of high temperature electronics providing smart actuators and control technologies to work in the hostile engine environment.

Significant progress was made on development of an improved JP-8 (JP-8+100) fuel to reduce engine and aircraft fuel system fouling and coking. The program has continued to support the Air National Guard in flight demonstrations. The use of JP-8+100 has increased the time between augmentor anomalies, reduced fuel control change-outs, and reduced fuel system maintenance.

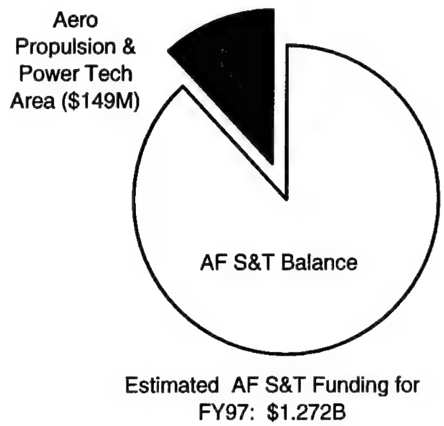

Figure 1.2: Aero Propulsion & Power S&T funds vs. AF S&T funds

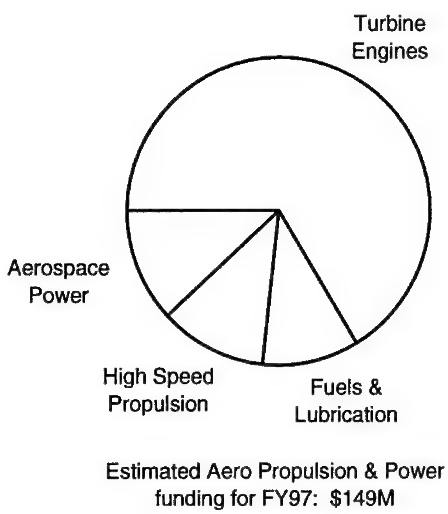

Figure 1.3: Major technology thrusts funding

The need for improved missile kinematic performance is being fulfilled by developing ducted rocket propulsion technology for advanced air-to-air missiles. Successfully demonstrated were a nozzleless booster producing the highest total impulse ever achieved, excellent gas generator performance under the worst external thermal loads, and flightweight ducted rocket engine support equipment over the operational envelope.

R&D success is achieved when relevant technology is truly available for transition to the operational world. The maintenance free battery program will successfully transition a maintenance free battery/charger system to the E-8 Joint Strategic Target and Recognition System (JSTARS). In addition to the battery program, development of a highly reliable 270-Vdc electrical power distribution system has been strongly endorsed by the F-22 System Program Office (SPO). Also, we continue to work with the C-141 Electric Starlifter program in retrofitting hydromechanical actuators of the aileron system with new electrically-driven, integrated actuator packages.

Regarding funding, Figure 1.2 shows the amount of money in the Air Force science and technology (AF S&T) program devoted to Aero Propulsion and Power. This funding along with program milestones are contained in the following Descriptive Summaries provided to Congress:

- PE62203F - Aerospace Propulsion,
- PE62269F - Hypersonic Technology Program,
- PE63202F - Aircraft Propulsion Subsystem Integration, and
- PE63216F - Aerospace and Propulsion Technology.

The funding supports our four thrusts: (1) Turbine Engines, (2) Fuels and Lubrication, (3) High Speed Propulsion, and (4) Aerospace power. They were created to exploit new technologies, while maintaining a balance with user needs. Figure 1.3 shows how Air Force S&T funds – including payroll and operation costs – are apportioned across these thrusts.

Work in our technology area is augmented by a very active Small Business Innovation Research (SBIR) program. We currently fund over 46 active contracts valued at $11 million. The Air Force Office of Scientific Research (AFOSR) sponsors 8 basic research projects valued at about $5 million per fiscal year. This work is reported in the AFOSR Research Technology Area Plan (TAP). The Reliability & Maintainability Technology Insertion Program (RAMTIP) provides an additional $1 million to develop electric actuators and ceramic bearings. Discussed next are the objectives and contents of each thrust.

THRUST 1, Turbine Engines, provides the Air Force's (and most of the nation's) turbine engine technology base. Work is centered on the IHPTET program. This is DoD's highest priority effort in air breathing propulsion R&D. IHPTET encompasses the three services, DARPA, NASA, and the domestic turbine engine manufacturers. It offers breakthrough opportunities and is revolutionizing flight vehicle range, payload, agility, survivability, supportability, and affordability. A fully supported IHPTET program will ensure American dominance in this key technology area well into the next century.

THRUST 2, Fuels and Lubrication, supports DoD user requirements with improved, environmentally acceptable fuels, combustors, lubricants, and lubrication systems. Thrust goals emphasize reducing both maintenance and waste in current systems while providing higher temperature capability to support current and future weapon systems. A far-term coal-derived fuel program is being pursued to assure national energy self-reliance. Being addressed are environmental concerns, fuel costs, and logistics. Much of this technology transitions directly to operational systems with little or no additional development.

THRUST 3, High Speed Propulsion, performs the only Air Force research and development in high speed airbreathing propulsion. A major portion of the effort supports the Hypersonic Technology (HyTech) program. The HyTech program is developing technologies that will enable sustained hypersonic flight. Combined cycle engines are being developed for high speed manned vehicles. These engines are being jointly developed with NASA and utilize turbomachinery technology developed under the IHPTET program. Tactical missile propulsion needs are being addressed that offer significant improvements in missile range, average velocity, and no-escape zones.

THRUST 4, Aerospace Power, provides a common technology base from which power systems can be developed with confidence. The More Electric Aircraft initiative is a major work effort focused on air vehicles. Led by the Air Force, this initiative leverages support from the three services, NASA, and over 50 individual companies. Emphasis is on reducing the cost of force projection by doubling power system reliability and reducing our dependence on aircraft ground support equipment. Also, this thrust – as well as 1 and 2 – combine resources toward the demonstration of distributed electric engine controls, magnetic bearings, and internal starter/generators. These are enabling technologies supporting the achievement of IHPTET's and MEA's aggressive goals.

Relationship to other technology programs

Aero Propulsion and Power is a broad-based area that deals primarily with energy and its transformation. As such, it is closely linked with most of the other Air Force technology areas. Foremost of these are Air Vehicles (engine/airframe integration, thermal management, aircraft subsystems, flight control), Conventional Armament (missile batteries and engines), Materials (engine materials and lubricants), Manufacturing Technology (producibility), Avionics (high temperature electronics), Advanced Weapons (high power technology), and the AFOSR managed technology area, Research (compressors, heat transfer, combustion, plasma physics). This linkage has been extended to the other services and further documented under the DoD technology plan.

Turbine engine R&D, through IHPTET, is thoroughly integrated with that of other government organizations and with the nation's manufacturers. The area typically leverages slightly more than its annual funding through contractor Independent Research and Development (IR&D) efforts. IR&D is a major contributor in maintaining our technological superiority and is applied to both military and commercial products. These efforts provide aircraft engine enhancements that otherwise would not be available from DoD funds.

Joint planning activities for the More Electric Initiative have formed a strong coalition between the services and NASA. The Army now relies on the Air Force for all of its technology developments for aviation electrical power systems. Additionally, the Army and Air Force are teamed to insert more electric technologies into electric vehicles for tactical and nontactical applications. The Navy and Air Force are jointly developing advance power electronics for onboard ship power conditioning.

The Joint Aeronautical Commander's Group's Joint Planning Team for the MEA continues to benefit by leveraging the nation's IR&D resources in electric subsystems and componentry. Funding in More Electric IR&D technologies exceeds $20M per year across the participating companies.

All four thrusts have international ties with emphasis on those areas where we have the most to gain. Most important is high speed propulsion, an area that – because of its breakthrough potential – many other countries are aggressively pursuing. Congressional earmarked funds (Nunn amendment) are supporting international programs to augment our ducted rocket efforts with higher energy propellants, simplicity, reliability, and reduced costs. Also, several international data exchange agreements exist to enhance our ramjet, ducted rocket, and combined-cycle engine concepts. These efforts help us to gain technical insight and to leverage limited R&D dollars.

In regard to the civilian sector, spin-offs will continue to be both common and important. A large portion of our developed technologies eventually wind up in commercial airplanes. Indeed, Air Force S&T is largely responsible for maintaining American dominance and a favorable balance of trade in this key field. This is also beneficial, in that the Air Force often buys "commercial" aircraft and engines for its airlift fleet.

Changes from last year

New this year are Defense Technology Objectives (DTOs) that were jointly formulated by the services and are currently undergoing review by DDR&E. They state specific technology advancements to be developed and/or demonstrated that solves a technical barrier for a specified customer. We have seven evolving DTOs:

- Fighter/Attack/Strike Propulsion,
- Transport/Patrol/Helicopter Propulsion,
- Cruise Missile/Expendable Propulsion,
- JP-8+100/JP-900 Hydrocarbon Fuels,
- High Speed Propulsion,
- Hydrocarbon Scramjet Missile Propulsion, and
- Aircraft Power.

The DTOs account for over 95% of our S&T dollars and are joint/coordinated with the other services. They help us link technology efforts to specific goals that will provide the warfighter with discernible air vehicle capabilities.

Continuing this year is the expanded interest in solving durability issues – specifically, high cycle fatigue in turbine engines. This issue has been raised to the highest levels within DoD and a National Coordinating Committee has been formed to quantitatively define the challenge and identify necessary technology programs.

We have placed higher priority on the transition of IHPTET and MEA technologies to multiple customers, both military and commercial. Of special note is the emergence of the Joint Strike Fighter (JSF) program – that will demonstrate key propulsion and power technologies and system

designs necessary to meet both Air Force and Navy next generation strike aircraft needs. IHPTET and MEA technologies and demonstrations supply the foundation of the JSF propulsion and power effort.

Programs continue to be structured to assure technology insertion into fielded systems. Examples include programs to develop technology upgrades for existing and developmental engines. Efforts are underway to develop propulsion technologies – both turbine engine and ramjet – for low cost smart weapons.

Another major change from last year is the formation of the Wright Laboratory HyTech program. This nationally coordinated effort was established by direction of the Secretary of the Air Force. The objective is to develop and demonstrate critical technologies that "enable sustained hypersonic flight." These technologies are required to support hypersonic concepts that address documented user needs and deficiencies. Mach 4 to 8 high speed airbreathing propulsion is the current key enabling technology focus of the HyTech program.

Consortia between government/industry/academia are forming to work common technical issues. These consortia are cost effective partnerships that require large resources of capital. The result is win-win for the participants and for the country. Current partnerships are in the areas of advanced composites, instrumentation, forced response, life prediction, and damping.

With the draw-down in defense, we have become more actively involved in forming partnerships with industry and academia. We are taking advantage of our in-house strengths to develop Cooperative Research and Development Agreements (CRDAs) with nonfederal partners to enhance technology transfer. Neither the military nor commercial world can afford to fully fund all research and development efforts required to maintain our technological edge in the international market. However, since much of our technology has dual-use potential, we are able to leverage our resources with industry in order to develop technologies that benefit both military and commercial applications. This enables the nation to effectively compete in the international market.

Summary

Our technology area plan describes a well-balanced program that:

- Is focused on user priorities,
- Is responsive to policy guidance,
- Exploits technological opportunities and revolutionary approaches, and
- Leverages budgets through extensive cooperation with other laboratories, agencies, and industry.

The chapters that follow highlight our four thrusts. Described are user needs/deficiencies, goals, major accomplishments, changes from last year, and milestones. These chapters represent our strategy to meet the current and future needs for defense research and development.

Thrust One – Turbine Engines

User needs

Airbreathing propulsion is a key DoD technology that this thrust supports through the Integrated High Performance Turbine Engine Technology (IHPTET) program. IHPTET is a joint DoD/NASA/industry program focused on developing turbine engine technologies for more affordable, more durable, higher performance military propulsion systems. Because gas turbine engine technology is largely applicable to both military and civil aircraft, achieving the IHPTET goals will help to ensure continued U.S. preeminence in the increasingly competitive international marketplace well into the 21st century. IHPTET is strongly supported by Congress and is often cited as the premier example of a well coordinated government-industry technology development program. It offers step-wise (phased) technology transitions for various engine classes to targeted weapon system applications as shown in Figure 2.1.

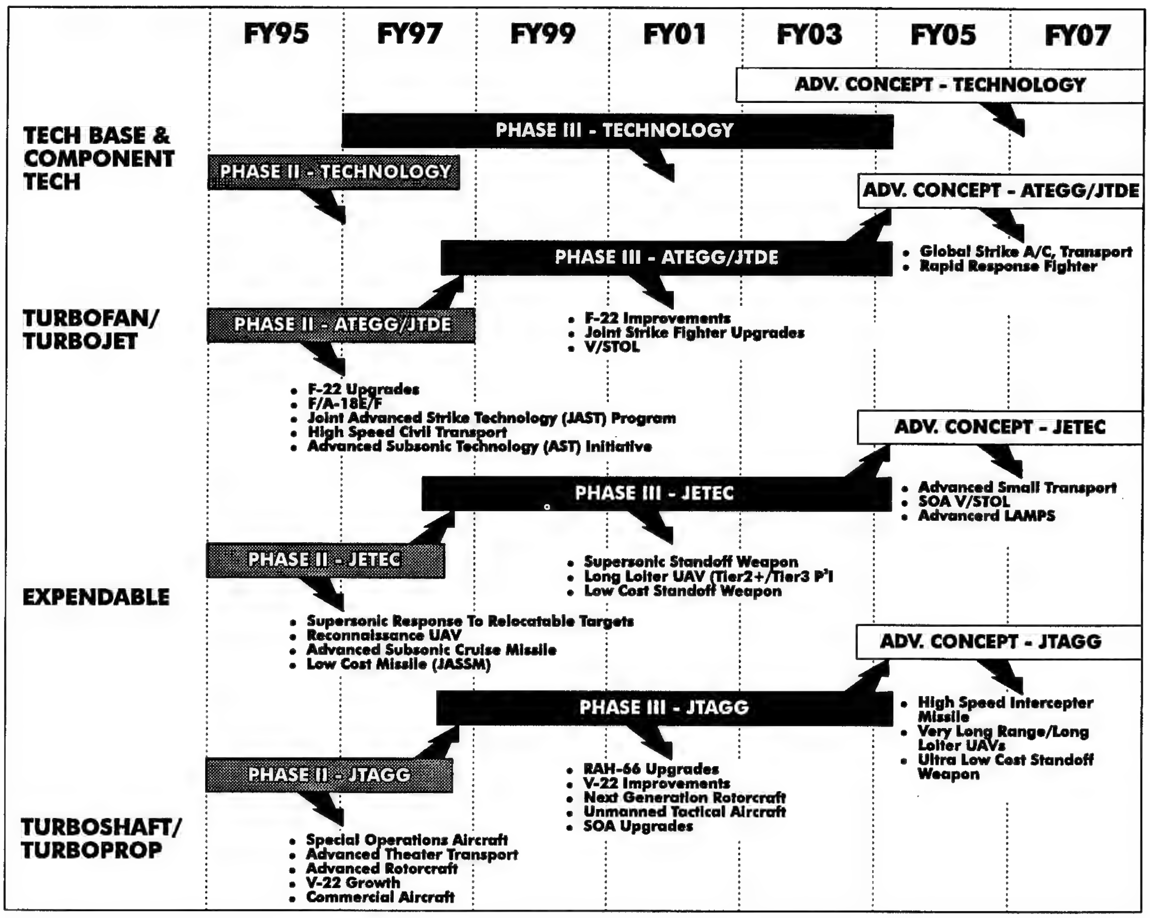

Figure 2.1: Thrust 1 – Turbine Engines

Although IHPTET Phase III is scheduled to be completed in 2003, the Air Force, Army, and Navy have begun planning the next revolution in turbine engine technology capability – we call it **Advanced Concepts**.

Historically, the propulsion system (engines plus fuel) accounts for 40% to 60% of aircraft takeoff gross weight and 20%-40% of the aircraft acquisition and operation costs. Accordingly,

increasing engine performance and reducing engine costs are major contributors to improving future air platform capability.

In the nearer term, IHPTET technology is currently being transitioned to the following:

- F414 engine for the F-18E/F,
- F119 engine for the F-22,
- T406 engine for the V-22,
- T800 engine for the RAH-66,
- J407 engine for the Integrated Tactical Air Launched Decoy (ITALD), and
- Several civil engines such as the PW4084, GE90, FJ44, AE3007, and AE2100.

Future military transition opportunities include the following:

- Engine upgrades for the platforms listed above and the F-15, F-16, C-17, AH-63, UH-60, CH-47 and Tomahawk, and
- New systems such as the JSF, Common Light Vertical System Replacement, Ultra-low Cost Supersonic Standoff Weapon, Global Strike Aircraft, Rapid Reaction Fighter, Unmanned Fighters, or a long-range/loiter UAV.

IHPTET is also the primary building block for the National Transport Rotorcraft program and NASA's Advanced Subsonic Technology and High Speed Research programs directed specifically at civil engines.

To date, many user deficiencies involving turbine engine technology have been defined through the Technology Master Process. Those identified in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data report are summarized in Table 2.1.

Table 2.1: Consolidated list of deficiencies and user/TPIPT reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Range / Endurance / Loiter Limitations	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Platform Acceleration (Thrust)	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Signatures of Aircraft Too High	ACC / Air-to-Surface, Rescue SOC / Special Operations Forces
Meet Noise and Emission Standards	AMC / Mobility SOC / Special Operations Forces
Lack of Engine Commonality	ACC / Rescue SOC / Special Operations Forces

In all cases, the IHPTET program is positioned to either deliver demonstrated technologies to the user or has an aggressive technology development plan underway – thereby lowering the user's technology introduction risk. Nearly all nearer-term needs call for "reduced engine acquisition cost and reduced cost of ownership" as a fundamental requirement along with increased durability, repairability, maintainability, supportability, and performance (thrust-to-weight and fuel consumption). To increase attention on cost reduction issues, programs have been structured to integrate IHPTET designs with advanced manufacturing processes to reduce all aspects of cost for new, derivative, and upgrade engines. Other methods for meeting the user defined deficiencies include the following:

- Maximize design application of new knowledge.

- "Swept aero" provides higher pressure ratio in fewer compressor stages, a 3-5% higher efficiency, and greatly increased ruggedness. It is also an excellent example of a dual-use technology. If applied across the U.S. military and civil aircraft fleets, swept aero designs would save $1 billion per year in fuel use alone. The first fan design with IHPTET derived swept aerodynamics is now in production in the FJ44 engine. This engine is used by both a commercial business jet and an unmanned air vehicle (Dark Star).
- "Super-cooled" turbine blade designs permit 300° F higher gas temperature for increased thrust, or 30% reduction in blade cooling air for reduced fuel consumption, or 2- to 4-fold increase in turbine blade life – all at a reduced manufacturing cost. The potential for a $3 billion total Air Force life cycle cost savings by using "super cooling" in the F119 (F-22 engine), F100 (F-15, F-16 engine), and F110 (F-16 engine) has resulted in a strong "user pull." We are accelerating the technology development and transition to meet near-term user needs.
- Integrated low observable (LO) designs synergistically use IHPTET technology to reduce the manufacturing cost, weight, and performance penalties associated with stealth. Addressing LO requirements up front using an integrated product team (IPT) approach allows us to "build-in" rather than "bolt-on" stealth technologies, thus avoiding weight, cost, and maintainability problems.

■ Address engine noise generation.
  - Noise can place military transports and helicopter platforms at risk from an observability standpoint. Technologies such as our swept aerodynamics and variable cycle engine concepts address this deficiency.

■ Use the same technology twice.
  - "Common engine cores" can be used in a wide range of applications from multiple fighter engines, to high bypass-ratio engines for military and commercial transports, to industrial and marine engines. Over 75% of the DoD turbine engine technology investments are applicable to civil sector needs.
  - IHPTET provides the core engine base for the Advanced Subsonic Technology (AST) and High Speed Research (HSR) programs – two premier U.S. investments by NASA that are part of the national/civil sector aircraft gas turbine technology development plan currently being defined by DoD, NASA, and industry.

■ Tailor the engine performance during flight.
  - The Variable Cycle Engine (VCE) concept permits more efficient operation over a broader portion of the flight envelope. Specifically, the VCE concept should result in elimination of the augmentor with its attendant very high fuel usage and high signature, and the variable geometry exhaust nozzle with its high weight, complexity, and cost.

■ Provide supersonic engine technologies.
  - Focusing on minimum cross section, low weight, increased thrust, reduced acquisition and ownership costs for the Joint Strike Fighter (JSF).

■ Improve durability of current and future engines.
  - Eliminate/reduce high cycle fatigue (HCF) – one of the largest causes of fleet "stand-down," and
  - Avoid expensive mid-life design changes by designing robustness into components.

■ "Pump electrons" instead of hydraulic fluid, oil, or fuel.

- Develop a "distributed control system" in which the accessories are located where they are needed rather than at the end of the power take-off shaft. This dramatically improves the reliability and maintainability of our engines – a prime user concern.
- Eliminates the need for on-engine hydraulic systems, gearboxes, all associated plumbing, and some unique flightline specialists.
- Internal engine starter/generator technology eliminates the central hydraulic unit, the power takeoff shaft (the "umbilical cord" between the engine and aircraft), and the gearbox that are another major source of maintenance actions.

In summary, all programs in this thrust are focused on meeting the IHPTET goals that, in turn, support the current user defined deficiencies. Special emphasis is being placed on resolving HCF durability issues and on reducing acquisition cost.

Goals

Time-phased goals have been defined for three classes of demonstrator engines:

- Large pilot-rated **turbofan/turbojet engines** for fighters, bombers, and transports;
- Smaller pilot-rated **turboprop/turboshaft engines** for trainers, rotorcraft, special operations aircraft and theater transports; and
- **Expendable engines** for cruise missiles and unmanned air vehicles (UAVs).

The specific IHPTET goals for each engine class are:

TURBOFAN / TURBOJET:		
■ Phase I (1991) +30% thrust/weight -20% fuel burn	■ Phase II (1997) +60% thrust/weight -30% fuel burn -20% production cost -20% maintenance cost	■ Phase III (2003) +100% thrust/weight -40% fuel burn -35% production cost -35% maintenance cost
TURBOSHAFT / TURBOPROP:		
■ Phase I (1991) +40% power/weight -20% SFC	■ Phase II (1997) +80% power/weight -30% SFC -20% production cost -20% maintenance cost	■ Phase III (2003) +120% power/weight -40% SFC -35% production cost -35% maintenance cost
EXPENDABLES:		
■ Phase I (1991) +35% thrust/airflow -20% SFC -30% cost	■ Phase II (1997) +70% thrust/airflow -30% SFC -45% cost	■ Phase III (2003) +100% thrust/airflow -40% SFC -60% cost

The time-phased approach of the IHPTET program allows for continuous technology transition, reduces technical risk, and defines interim milestones against which progress is assessed.

Examples of system level payoffs from achieving the challenging IHPTET goals include:

- Intercontinental range in an Air Launched Cruise Missile (ALCM)-sized missile,
- Five-fold increase in speed for tactical cruise missiles,
- A 100% increase in range/payload for both attack aircraft and helicopters with enhanced maneuverability,
- A sustained Mach 3+ capability in an F-15-sized aircraft,
- 35% reduction in gross weight and production cost for a new fighter,

- A 100% increase in unmanned aerial vehicle endurance, and
- Greater range/payload capability in an F-18-sized STOVL aircraft.

Major accomplishments

During the past year, we met IHPTET's Phase I goals for turboshaft/turboprop engines. These include 40% increase in power-to-weight ratio and 20% reduction in fuel consumption. IHPTET Phase I is now complete and Phase II is well underway in all three classes of engines.

Cost goals for both turbofan/turbojet and turboshaft/turboprop have been adopted by the IHPTET Steering Committee. In support of the maintenance cost goal, a detailed technology development plan for HCF was defined and presented to the newly formed HCF S&T National Coordinating Committee. The HCF plan includes Air Force, Navy, and NASA efforts including three consortia with industry, namely, Forced Response, Instrumentation, and the newest consortium on Damping.

Additional testing of key IHPTET technologies continued in dedicated structural/environmental advanced technology demonstrators. These durability "shakedowns" reduce the risk of technology introduction into future and current systems, lead to improved performance and capability, and ultimately result in significant life cycle cost (LCC) reductions. The payoffs for the F119 include system LCC savings of $420 million plus 10-20% thrust increase, 2-5% specific fuel consumption (SFC) decrease, and 15-20% cost and weight reduction for the augmentor and exhaust nozzle. For current engines, the payoffs include system LCC savings of over $1 billion plus doubled turbine life, reduced exhaust signatures, improved operability, and increased aircraft range.

Changes from last year

Our focus on achieving the challenging IHPTET goals is unwavering. Some programmatic changes have occurred to further demonstrate IHPTET technologies in response to recently defined user needs and renewed interest in UAV applications.

The most profound change has been the renewed and expanded interest in solving durability issues – specifically, high cycle fatigue. HCF is now an AFMC/ST Focus Area and has been raised to the highest levels within DoD. A National Coordinating Committee has been formed to bound the problem and ensure that all necessary technology programs are being pursued.

The Air Force/Industry Affordability Working Group continued to accelerate efforts for reducing the acquisition, operation, and support costs of turbine engines. As a result of this group's recommendations, cost reduction goals for IHPTET were formally accepted for the turboprop/turboshaft engine class. Acquisition cost reduction, measured in dollars per pound of thrust and maintenance cost reduction, measured in dollars per thousand engine flight hours per pound of thrust, are the two new goals.

Of special note is the emergence of the JSF program – IHPTET technologies and demonstrations continue to serve as the foundation of the JSF propulsion effort.

Milestones

Selected milestones towards achieving the IHPTET goals are:

- Core engine test of third generation supercooled turbine blades for longer life and increased performance – first quarter FY97,
- Demonstrator test of advanced variable cycle engine concept – third quarter FY97,
- Engine test of high temperature metal matrix composite disk compressor – fourth quarter FY97,
- Engine test fluidic control of exhaust area and thrust vectoring for reduced complexity/weight – second quarter FY98,
- +200° F combustion initiation temperature capability – second quarter FY99,
- Core test of full-up magnetic bearing system – first quarter FY00, and
- Core test of advanced fuel-cooling concept – first quarter FY00.

Thrust Two – Fuels & Lubrication

User needs

The Fuels and Lubrication thrust advances the pervasive technologies of aircraft and airbreathing missile fuels, combustion, lubricants, and lubrication systems. This thrust is structured in response to Mission Area Plans (MAPs) and associated weapon system user needs. These needs are identified through the Technology Master Process (TMP) that provides unified guidance to the Air Force laboratories and thereby provides a basis for focusing laboratory thrusts to address current and projected user needs. These needs/deficiencies are reported in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data document prepared by Aeronautical Systems Center (ASC) for Air Force Materiel Command (AFMC). Weapon system deficiencies we currently address are shown in Table 3.1.

Table 3.1: Consolidated list of deficiencies and user/TPIPT reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Increased range / endurance	ACC / Aerospace Control, Air-to-Surface
Improved reliability, maintainability, repairability	ACC /Aerospace Control, Air-to-Surface AMC / Mobility
Reduced signature (IR, visual, acoustic)	ACC / Aerospace Control, Air-to-Surface, Rescue SOC / Special Operations Forces
Thermal burden (cooling capacity)	ACC / Aerospace Control, Air-to-Surface, Intelligence, Surveillance, and Reconnaissance
Increased engine performance	ACC / Aerospace Control
Pollution compliance	ACC / Air-To-Surface AMC / Mobility

Our primary customers are the Air National Guard, Air Education and Training Command, Air Combat Command, Special Operations Command, Combat Search and Rescue, and Air Mobility Command. Their needs cross many command/theater boundaries.

Goals

Specific goals have been formulated to address user needs as shown in Table 3.1. These are quantified and timed phased with the IHPTET and HyTech programs.

- Improved fuels, aircraft thermal management, and cooling capability,
- Advanced combustor concepts, modeling and diagnostics, and reduced engine emissions,
- Improved engine lubricants and lubrication system mechanical components, and
- Increased reliability and supportability through reduced maintenance and lower life-cycle-costs.

Major accomplishments

High Temperature Fuels:

During the past year, significant progress was made on development of an improved JP-8 (JP-8+100) fuel to reduce engine and aircraft fuel system fouling and coking. The program has continued to support the Air National Guard with F-16 flight demonstrations at Kingsley Field, OR. The use of JP-8+100 increased the time between fuel-related augmentor anomalies by 340%, reduced fuel control change-outs by 80%, and reduced fuel system maintenance by $268 (70%)

per flight hour. These savings translated into a cost avoidance of over $825,000 for this guard unit during the one year period. Additional flight demonstrations in F-15s, T-37s, T-38s, A-10s, and C-130s are underway with other guard and training units. These demonstrations will provide needed performance data for the +100 additive across several engines and airframes.

Another important facet of the JP-8+100 program includes material compatibility testing. This involves evaluating the impact (if any) of candidate +100 additive packages on metallic and nonmetallic materials (approximately 170) contained in the engine and airframe. To date, 111 materials have been tested with two additive packages with no detrimental effects noted. Testing was a joint development effort between the lab and industry.

Current fuel system icing inhibitors are toxic and will be regulated under pending Environmental Protection Agency clean air and water act legislation. Several candidate environmentally safe, nontoxic fuel system icing inhibitors derived from sugars were synthesized and tested in the laboratory. The new materials developed, under a joint program with the Navy, are nontoxic and environmentally benign.

Lubrication Systems:

Liquid lubricant development is focused on IHPTET propulsion technology goals. It is closely coordinated with lubricant base material and additive research efforts in the Materials and Processes technology area and with related government, academic, and industrial research centers. Three vendors have now been qualified to produce our most advanced, fleet-ready lubricant. Designed to meet the demanding temperature limits of the F-22 aircraft, this lubricant offers excellent thermal stability up to 400 °F and exhibits reduced carbon deposition tendencies.

Vapor phase lubricant technology continues to show promise in addressing expendable engine requirements. In concert with industry and private research groups, a vapor phase lubrication system is being designed for a FY97 IHPTET Phase II Joint Expendable Turbine Engine Concept (JETEC) demonstrator. The technology has been fully demonstrated in rig tests. When implemented into an advanced missile engine, vapor phase lubrication will eliminate the need for 80% of a conventional liquid lubrication system.

Development efforts continue on sensors to detect the presence of hazardous and reclamation-inhibiting contaminants in waste/used turbine engine oils. This development has led to a simple, effective, and environmentally responsible process for segregating and recycling used oils. Prototype sensor packages, both hand-held and flow-through, have been evaluated by the Navy. The hand-held detector proved to be simple, quick, and sufficiently accurate to perform quantitative field tests on oil samples, replacing the current more costly and tedious test methods.

Mechanical Systems:

Thin-dense chrome (TDC) coated turbine engine bearing races were evaluated in a comprehensive series of performance and endurance tests and in full-scale engine tests. Results are being evaluated to determine if these bearings should be incorporated into the F110 engine bill of material. It has been estimated that $14 million per year could be saved by providing corrosion and debris damage resistance to all Air Force aircraft engine bearings.

Ceramic rolling elements in bearings provide life, corrosion resistance, and improved "oil-off" operational benefits. The No. 3 bearing in the F117 engine (C-17 aircraft) is being qualified with ceramic elements and is expected to transition in 1997.

Combustion:

Joint studies involving government, industry, and academic laboratories have yielded the first-ever ultrafast pump/probe laser image. This effort is part of our continuing development of laser-based combustion diagnostics. This technology is critical to developing diagnostics to study

combustion and advanced combustors. These diagnostics are used to validate computational models and to provide vital engineering feedback on combustor hardware.

A time-dependent model with chemistry was developed to study combustion flames. This is the first time a complete simulation of combustion involving opposing fuel and air jets has been made. These simulations yield more reliable predictions than those from conventional analyses. An experimental and computational study determined that the lack of perfect mixing represents an inefficiently burning combustion system. These findings are expected to have a large impact on turbulent combustion model development.

A unique combustor has been designed in-house that utilizes a trapped vortex to provide flame stability. This simple and compact combustor shows excellent promise for combustor applications. The flame is stable over a fuel-to-air ratio range 10 times greater than conventional combustors, resulting in reduced flameouts. Overall pressure losses through the combustor are lower. In addition, the combustor produces greatly reduced oxides of nitrogen (NO_x) – an ozone depleter – while maintaining a combustion efficiency exceeding 99%. A combustor, based on the trapped vortex design, is being proposed by a prominent engine contractor for IHPTET Phase III.

Field Support:

In addition to developing technology to support critical operational deficiencies, our expertise has been in high demand in solving unexpected field problems. This past year we:

- Isolated the cause of failure in five C-17 integrated drive generators and developed a short-term solution enabling deployment of the aircraft to Bosnia, and a long-range, fleet solution,
- Determined the cause of a rash of C-130 gear box failures and instituted safeguards against future failures,
- Participated in the investigation of a C-21, Class A accident and conducted the fuel and oil analysis, and
- Participated in restructuring the Air Force Oil Analysis Program.

Changes from last year

Continued strong support from the Air National Guard has led to expanded field demonstrations of JP-8+100 and also led to programs to determine the impact of the additive on ground handling equipment. A significant concern has been found with existing filter coalescer technology that limits fleet-wide implementation. Resources to address this problem will not be available until FY98. As a result, the time for issuing the final specification for the improved JP-8 (JP-8+100) has slipped two years to FY00. Follow-on programs, such as JP-900 and endothermic fuels, have been slipped accordingly.

In a joint effort with industry and the Materials and Processes technology area we are developing what is believed to be the most advanced synthetic ester-based lubricant possible. Dubbed the "optimal ester" the new material will be capable of sustained operation at 450° F, and enable systems such as Joint Strike Fighter (JSF) aircraft to fully utilize the heat sink potential of JP-8+100 fuel. The maximum operating temperature of current lubricants represents the limiting fluid temperature of JSF thermal management concepts.

In past years, Lubricants and Lubrication Systems were reported as separate subthrusts. Beginning with this TAP, these technologies are now folded into a single subthrust titled Lubrication Systems. The change reflects the fact that the boundary between the technologies is no longer relevant. Temperature and load conditions in engine applications are such that bearings (lubrication system) and lubricants are selected or designed to function synergistically.

Milestones

- The C-17 aircraft engine hybrid ceramic bearing program, funded by DARPA, will finish in FY97 producing a more durable bearing.
- The final specification for an improved JP-8 fuel (JP-8+100) will be released in FY00 with a qualified product list of additives.

Selected milestones documented in the DoD technology plan are:

- Demonstrate by 1998 a 100° F increase in thermal stability and a 50% increase in heat sink capability for JP fuel.
- Demonstrate by 2005 a 5-fold increase in fuel cooling capability using JP-900 and a 5- to 10-fold increase in fuel cooling capability using alternative high heat sink hydrocarbon fuels (endothermic).

Figure 3.1 outlines the specific timelines for milestones in the three major technology areas being pursued.

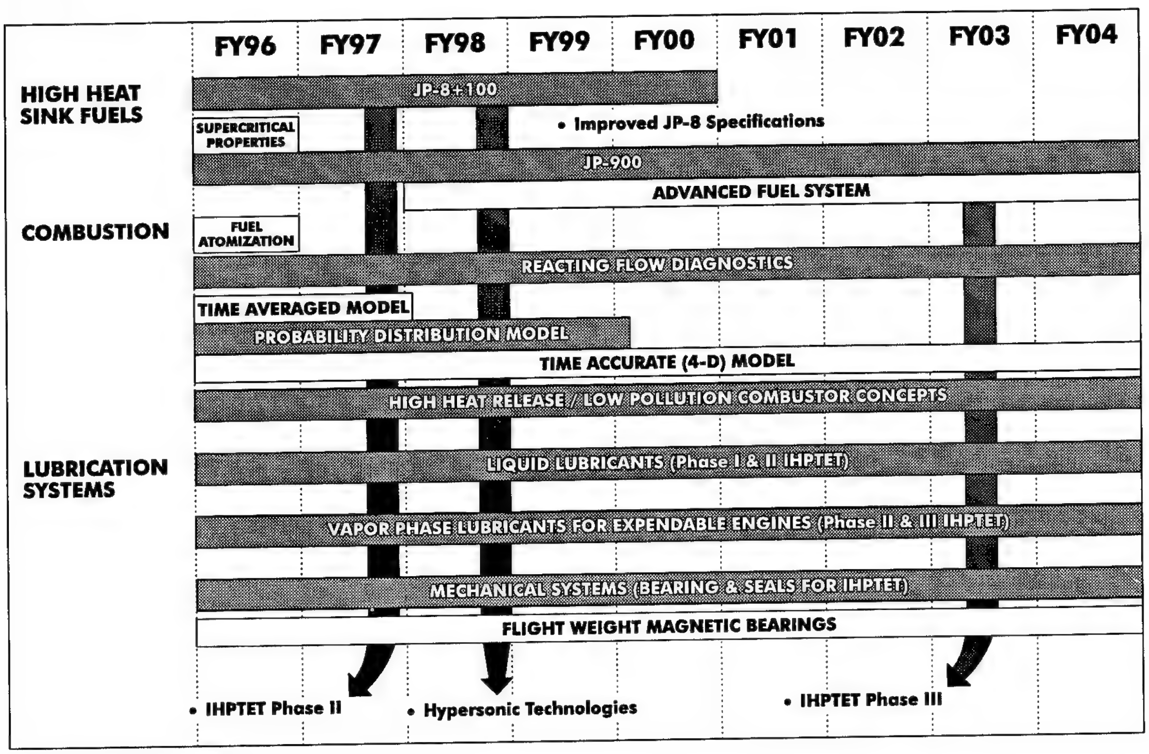

Figure 3.1: Thrust 2 – Fuels & Lubrication

- **High Heat Sink Hydrocarbon Fuels** are being developed to reduce operational and maintenance costs, increase reliability and readiness in current and derivative engines, and provide additional heat sink and thermal stability for future systems. Additional JP-8+100 additive candidates are being sought and tested to assure wider availability and to meet the cost goal of no more than one tenth of a cent per gallon of fuel. Research objectives have been outlined to ensure the improved fuel will be available for fleet-wide transition by FY00.

  Development of an advanced hydrocarbon fuel with a thermal stability up to 900° F (JP-900) and endothermic fuels offer solutions for significant improvement in aircraft thermal management with low maintenance and lighter fuel systems for high-speed air breathing missile propulsion systems. Endothermic fuels are essential for successful hydrocarbon

scramjet and combined cycle engine concepts. Responsive field support to help solve operational problems continues to be a high priority.

- **Combustion** research efforts are being conducted to reduce the risk and cost associated with developing affordable, durable, high performance turbine engines that operate efficiently within air pollution guidelines and have high thrust-to-weight ratio and low specific fuel consumption. Research directed at providing high heat release capability for IHPTET Phase III combustors has been expanded to include the control of NO_x at high power and unburned hydrocarbons and carbon monoxide at low power.

  Replacement fire suppressant agents for the banned Halon 1301 will be evaluated to determine the optimum replacement and to better understand the extinguishing mechanism. This information is vital to specifying the agent delivery systems and the quantities of agent to be loaded into a particular fire suppressant system.

- **Lubrication Systems** address the challenge of supporting and controlling turbine engine rotors and the mechanical power extraction systems. Key components include the lubricant, bearings, air-oil seals, dampers, and gears. Technology drivers include enhancing operability, maintainability, readiness for fielded engines, and meeting higher temperature and rotational speed requirements of IHPTET demonstrator engines.

  Fielded systems continue to benefit from advances in lubricant and bearing temperature tolerance, in oil diagnostic techniques for engine condition monitoring, and in contaminant identification technology for used oil segregation and recycling.

  Advanced systems require aggressive developments in component performance and durability, while making the systems more affordable. Specific requirements vary with application. For man-rated IHPTET applications, high performance, yet affordable, systems with high durability and reliability are emphasized. Expendable IHPTET concepts emphasize low cost as well as high performance. Innovative support system concepts must be employed to meet the IHPTET Phase II and Phase III goals. Currently under development are systems to operate with high temperature liquid lubricants, various forms of solid lubrication, and vapor phase lubrication. Active magnetic bearings, another revolutionary concept under development, are essential for successful Phase III IHPTET technology demonstrator engines.

Thrust Three – High Speed Propulsion

User needs

The High Speed Propulsion thrust is focused on the Air Force Vision "Global Reach - Global Power." In support of this vision, this thrust provides Mach 0 to 8 air breathing engine technology for advanced missiles, aircraft, and space launch vehicles. The thrust provides development and demonstration of unconventional air-breathing propulsion systems such as ramjets, scramjets, and combined/advanced cycle engines to ensure propulsion options for future high speed, rapid response air defense systems.

As the Air Force's only work in high speed airbreathing propulsion, this thrust plays a vital role in retaining the research base necessary to maintain our technological edge and to satisfy Air Force needs and deficiencies identified by Mission Area Plans (MAPs) and developed by Technical Planning Integrated Product Teams (TPIPTs) as part of the Technology Master Process (TMP). Aeronautical systems needs we address are documented in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data report. Appropriate far-term space launch needs have also been identified by the Air Force Space Command (AFSPC). The Scientific Advisory Board New World Vistas study endorsed hypersonic propulsion as a key technology required to meet Air Force needs in the 21st century. Table 4.1 lists specific deficiencies for both aeronautical systems and space launch vehicles that are addressed by our enabling technologies.

Table 4.1: Consolidated list of deficiencies and user/TPIPT reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Increase missile kinematics and capability to kill time critical targets	ACC / Aerospace Control
Ability to destroy targets from standoff ranges and ability to destroy time-critical targets	ACC / Air-to-Surface
Rapid response capability against theater and ballistic missiles	ACC / Theater Missile Defense
Cost effective space lift capability that enables timely support of military forces	AFSPC / Spacelift
Multiple high speed system concepts	ACC / Intelligence, Surveillance, and Reconnaissance; Counterair; and Suppression of Enemy Air Defenses AMC / Mobility

Realizing the potential payoff for high speed airbreathing propulsion will mark a major step increase in weapon system performance and cost effectiveness. High speed vehicle propulsion will be critical to meet worldwide requirements as we continue to reduce overseas forces and forward basing. To manage the required technology development programs, the High Speed Propulsion thrust is divided into three technology areas (subthrusts): ramjets, scramjets, and combined cycle engines – each providing unique capabilities for the user.

Ramjet efforts are focused on missile propulsion systems that revolutionize air combat and surface strike capabilities. Flight ready ducted rocket engine technology will nearly double the engine total impulse of similar size conventional solid rockets, resulting in a dramatically increased missile kinematic capability. As a result, several-fold improvements in aircraft combat exchange ratios are attainable through increased missile lethality and launch aircraft survivability.

Specific improvements in missile kinematic capability include increased no-escape zone, launch range, and a reduction in time-to-target. This technology provides the capability to meet current and emerging foreign air-to-air missile threats. Additionally, ramjet powered high speed air-to-ground missiles reduce time-to-target 50% and provide the terminal kinetic energy required to strike hardened or deeply buried targets with up to 1000 nautical mile standoff ranges.

Combined cycle engine and scramjet propulsion systems offer enormous payoff for future missiles, aircraft, and space launch vehicles. Their two to three times efficiency improvement over rocket engines enable the design and development of lighter engines and smaller hypersonic vehicles. These benefits can be realized, for example, through lighter air-to-ground weapons that rapidly attack time critical and hardened or deeply buried targets (lethality); provide long-range standoff capability (aircraft survivability); launch from tactical or strategic aircraft (combat flexibility); allow increases in loadout (force multiplication); and reduce requirements for overseas basing and aircraft (affordability).

Mach 8 hydrocarbon fueled scramjet engines will provide the capability to attack highly mobile "SCUD-type" weapons from 300 nautical miles in less than 5 minutes or strike targets 1000 miles away in just 15 minutes. Mach 5 combined cycle engines enable tripling unrefueled tactical aircraft ranges from 300-500 miles to 1000-1500 miles without increasing mission flight times. Future continental U.S. based combined cycle and scramjet propelled Mach 10 aircraft could reach any military target in 2 hours. Other high payoff scramjet and combined cycle engine applications include reusable single-stage and two-stage-to-orbit launch vehicles that increase payload, thus providing more affordable access to space.

All Air Force High Speed propulsion efforts are coordinated and/or conducted jointly with NASA, Navy, and Army counterparts, as well as industry and universities, to provide a nationally unified high speed propulsion program. Figure 4.1 shows program development through the turn of the century and indicates points of transition to weapon system applications.

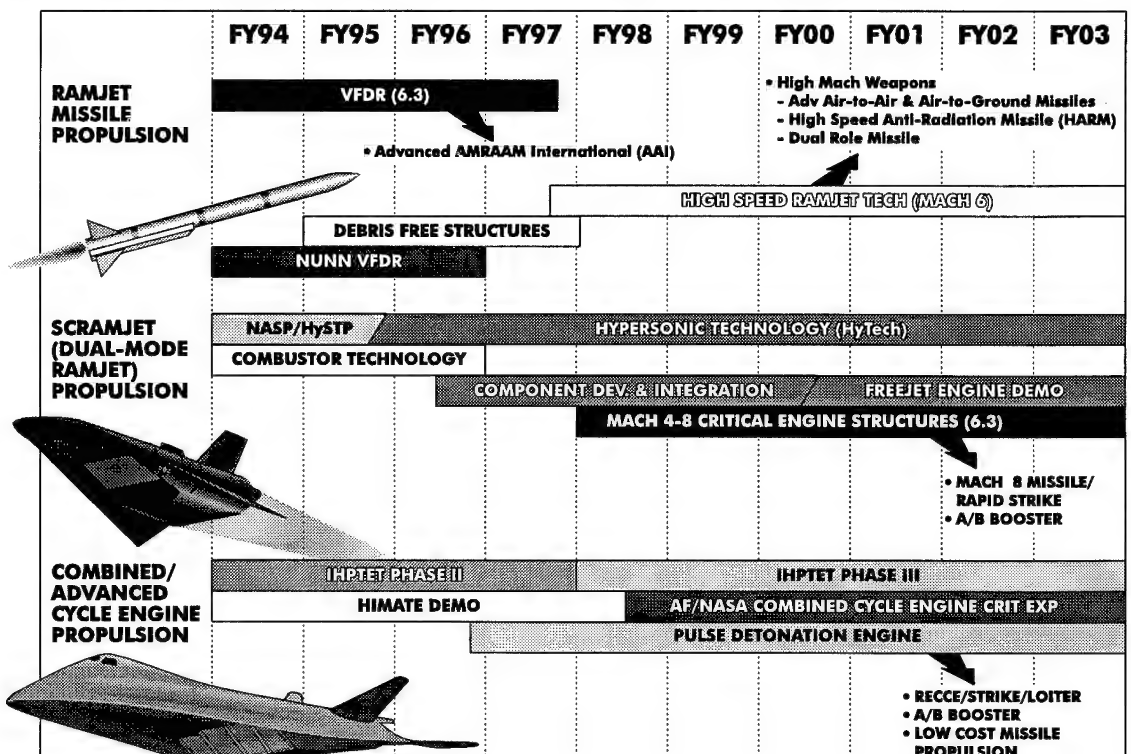

Figure 4.1: Thrust 3 – High Speed Propulsion

Goals

The goal of the High Speed Propulsion thrust is to address the deficiencies and user needs identified in the MAPs and TPIPT process. This will be accomplished by balancing performance, supportability, and costs of both upgrades and new high speed, long range propulsion systems. The two main objectives of the High Speed Propulsion thrust are as follows:

(1) Double missile propulsion capability by FY97

This objective is being addressed via the Variable Flow Ducted Rocket (VFDR) program. VFDR engine technology nearly doubles the engine total impulse over similar size conventional solid rocket engines. The VFDR engine uses an integral rocket to boost the missile from the launch aircraft to ramjet takeover speed. The engine then transitions to highly efficient ramjet operation and accelerates to Mach 3.5 using atmospheric air and onboard fuel for combustion.

Additional technologies supporting this goal include the development of consumable structures to reduce missile weight and drag, and eliminate hazardous ejecta. Joint international programs are focused on developing ducted rocket fuels with 50% higher volumetric energy than current fuels and developing simpler/cheaper ducted rocket engine configurations. New efforts will focus on expanding ramjet operation to Mach 6 for future missile applications.

(2) Provide Mach 0-8 hydrocarbon fueled propulsion capability for the 21st Century

Combined cycle and scramjet engine technologies using storable liquid fuels (JP like) will be developed for future missiles, aircraft, and space launch vehicles.

Scramjet engine technology is being developed under the Hypersonic Technology (HyTech) program. The objective of the HyTech exploratory development (6.2) program is to develop and demonstrate technologies that "enable sustained hypersonic flight." The technology will be proven through ground-test demonstration of a vehicle-integrated, flight-type scramjet propulsion system for a fast reaction, Mach 8 air-to-ground missile. The major challenge is demonstrating scramjet system performance, operability, and survivability in an integrated freejet engine test. Advanced development (6.3) will augment the HyTech program by demonstrating select structures, materials, and fuel technologies that are nearing transition readiness. This effort will serve as a stepping stone to future developments of scramjet powered high Mach vehicles.

Mach 0 to 6 combined cycle engine technology is being developed under the High Mach Turbine Engine Technology (HiMaTE) program. The goals are to demonstrate the air-core enhanced turbo-rocket critical engine component and the turboramjet variable area mixer/hyperburner. These engines are being jointly developed with NASA and will utilize turbomachinery technology developed under the IHPTET program. The solid fuel air-turborocket and pulse detonation engines (PDE) are being evaluated under several Small Business Innovation Research (SBIR) programs. The PDE shows promise as a low cost propulsion alternative for missiles and UAVs. Performance can be comparable to turbojets at low speed and better than ramjets at high speeds.

All engine systems being evaluated use storable hydrocarbon fuels. Use of these fuels will provide a dramatic advantage in supportability for future high speed systems. High Mach vehicles require fuels with a high heat sink capacity to cool hot engine and airframe components. Recent developments in high heat sink endothermic fuel technology (a fuel that absorbs a tremendous amount of heat through chemical decomposition) has enabled the use of conventional type jet fuels in high speed propulsion demonstration testing. Previous concepts and technologies were focused on using cryogenic hydrogen, requiring expensive "shuttle type" operations. With storable hydrocarbon fuels, airplane type operations for Mach 8 vehicles can be retained using current maintenance and fuel handling practices, enabling affordable and practical sustained high speed flight.

Major accomplishments

Major FY95/96 accomplishments in high speed propulsion include:

- Established an approved plan and initiated procurement for development and testing of a Mach 8 hydrocarbon fueled scramjet engine under the HyTech program.
- Demonstrated VFDR integral nozzleless booster performance at the required temperature extremes (-65° F to 145° F) and produced the highest total impulse ever achieved in this configuration. The butacene catalyzed booster propellant was approved for technology transition by the Aeronautical Systems Center.
- Demonstrated excellent VFDR gas generator operation and fuel flow rate control under the worst case external aeroheating thermal loads (high mach missile captive carry, launch, and free flight).
- Demonstrated flightweight VFDR engine support components. A preproduction arm/fire device successfully completed environmental verification and performance testing and was approved for technology transition. The torsion hinge assisted port cover was successfully demonstrated over the operational envelope.
- Demonstrated excellent combustion efficiency for Boron loaded ducted rocket fuels that offer 50% more energy than the baseline VFDR.
- Demonstrated a heavyweight proof-of-concept detonation tube for a pulsed detonation engine.
- Initiated performance testing of a baseline hydrocarbon fueled dual-mode ramjet/scramjet at Mach 4 to 7 flight conditions. Initial test results are very promising – combustion efficiency goals were achieved at several conditions.
- Initiated testing of an air-turborocket variable area mixer/combustor sector.

Changes from last year

The single major change to the High Speed Propulsion thrust has been the synergetic integration of the Wright Laboratory Hypersonic Technology (HyTech) program. The HyTech program was initiated by the direction of the Secretary of the Air Force, and will be jointly managed by Wright Laboratory's Aero Propulsion and Power Directorate, Flight Dynamics Directorate, and Materials Directorate. Moreover, the HyTech program is fully coordinated with other technology programs in DoD and NASA to ensure the development of hypersonic technologies is an integrated national effort that involves government, industry, and universities.

Milestones

The high speed propulsion thrust has established the following milestones for each subthrust (ramjets, scramjets, and combined cycle engines) to provide a timely, logical path to meet stated needs and goals.

Ramjet engine milestones supporting the VFDR engine include completing performance documentation and environmental testing (FY96); demonstrating engine boost-to-ramjet transition (FY97); and demonstrating all-up flightweight engines in freejet tests at the Arnold Engineering and Development Center (FY97). Joint international programs will document integrated engine performance of high energy boron fueled and passively throttled ducted rockets (FY96). Future ramjet programs will develop and ground demonstrate hydrocarbon fueled ramjet combustor technologies capable of efficient operation to Mach 6 (FY02).

Scramjet technology milestones are equally well established. Near-term activities include integrating an endothermic fuel heat exchange/reactor with an improved scramjet combustor to complete performance testing and expand the flight envelope up to Mach 7 (FY96). Future milestones established under the new HyTech program include establishing a concept

demonstration (FY96); further develop scramjet engine components (FY98); integrate scramjet engine components (FY00); and demonstrate scramjet engine performance, operability, and durability in an integrated engine freejet demonstration (FY02).

Combined cycle engine milestones include designing and fabricating a full annular air-core enhanced turbo-rocket (AceTR) critical component (FY96), and testing the AceTR critical component from Mach 0 to 5+ flight conditions (FY97). Turboramjet ramjet milestones are set to demonstrate the variable area mixer/combustor (FY96) and document hyperburner performance via direct connect testing (FY97).

The High Speed Propulsion thrust continues to explore and develop new and innovative high payoff propulsion cycles via SBIR programs. A low cost air-turbo rocket (ATR) monorotor (compressor and turbine cast in one piece) will be developed and demonstrated (FY97). A solid fuel gas generator with low slagging characteristics will be developed and tested for use with the monorotor (FY97). Finally, development of the pulse detonation engine will continue with the demonstration of a high frequency multitube engine for low cost, high speed missile applications (FY98).

Thrust 4 – Aerospace Power

User needs

The cost to produce, maintain, and support our high-tech weapon systems is one of the major issues the Air Force and DoD is facing. Technology options must be made available to ensure that aircraft designs are ultra-reliable, easier to maintain, supported by less equipment and personnel, more survivable, lower in cost, and higher in performance. Additionally, global economics are forcing our current fleet into extended service lives. To support and maintain this aging fleet, technology retrofit options must be focused on reliability, maintainability, and supportability (RM&S) and be made available in a cost effective and timely manner.

The challenge then, is to retain our strength and air superiority – but to do so with less. To address this challenge, we are focusing resources under the More Electric Aircraft (MEA) portion of the More Electric Initiative (MEI) toward electrically-driven subsystems in replacement of more conventional, less reliable hydraulics, pneumatics, and mechanically-driven subsystems. This "more electric" concept is made possible by the successful development and demonstration of critical technical areas such as power generation, power management and distribution, energy storage, and power systems integration. Figure 5.1 illustrates these technical area demonstrations enabled by the enhancement of key power components.

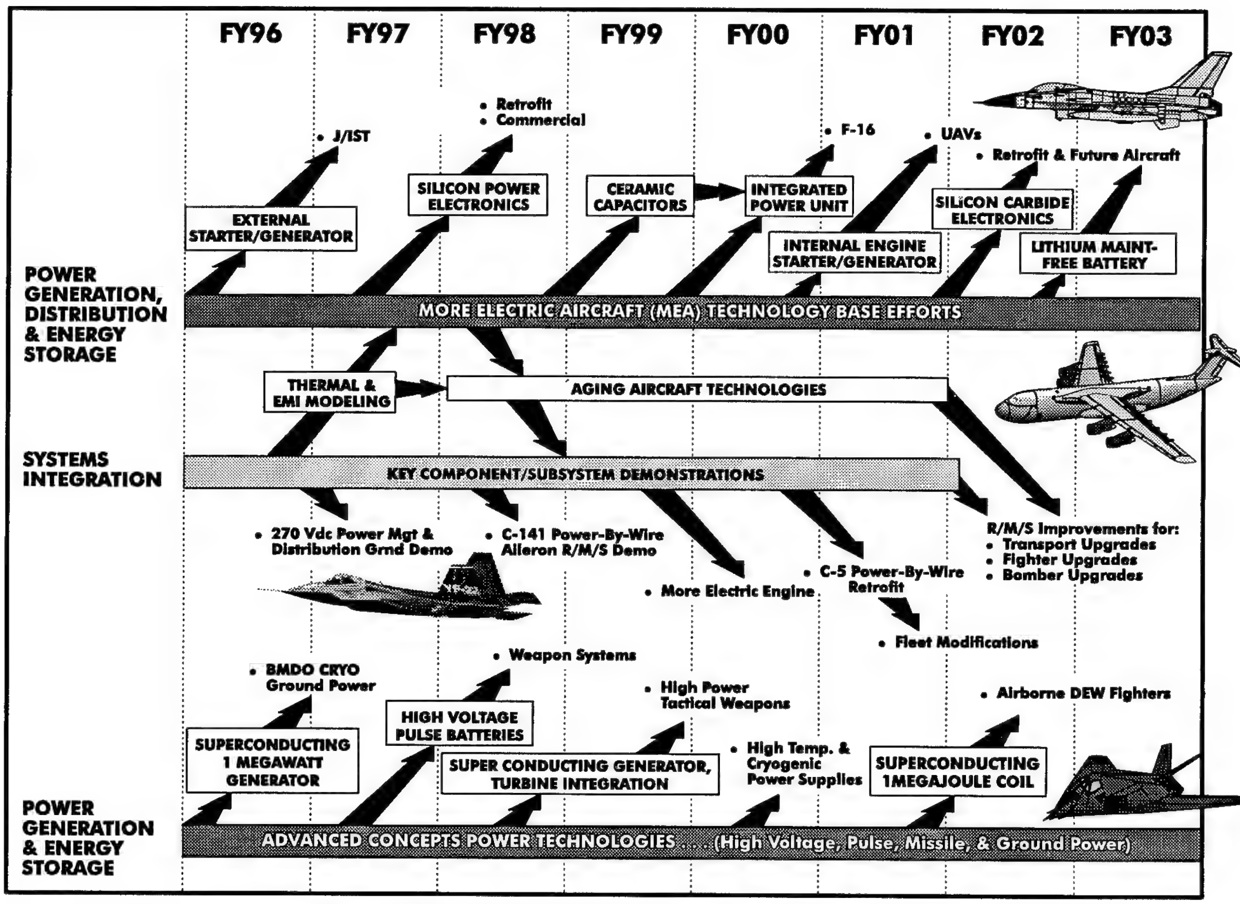

Figure 5.1: Thrust 4 – Aerospace Power

The "more electric" concept will not only reduce support equipment and costs, and improve our current aircraft effectiveness, but is also seen as the technology direction of opportunity relative to unmanned aerial vehicles (UAVs), commercial aviation, electric vehicles, and numerous other commercial applications as well as a variety of advanced weapon concepts.

MEA and advanced concept power technologies are responsive to these weapon system needs, identified by Mission Area Plans (MAPs) and developed by Technical Planning Integrated Product Teams (TPIPTs) as part of the Technology Master Process (TMP). Table 5.1 shows a consolidated list of deficiencies we address that are documented in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data report.

Table 5.1: Consolidated list of deficiencies and user/TPIPT reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Excessive support equipment / logistics tail	ACC / Aerospace Control, Air-to-Surface
Antiquated / unreliable secondary power system	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Large, heavy short-life batteries	ACC / Aerospace Control SOC / Special Operations Forces
Low aircraft subsystem / component reliability (MTBF) / maintainability	ACC / Aerospace Control, Air-to-Surface AMC / Mobility
Lack of electronic cooling technology	SOC / Special Operations Forces
Hazardous waste removal / disposal	ACC / Air-to-Surface

More specifically, through high payoff technology efforts and an aggressive retrofit focus in the areas of power generation, power distribution, energy storage, and power system integration, we will:

- **Reduce Support Equipment / Reduce Logistic Tail.** Relates to excessive manpower, support equipment, and readiness support package requirements necessitating significant airlift support; excessive and costly logistics tails and increased/complicated maintenance procedures required to sustain deployed force; lack of standardization across weapon systems, subsystems, and support equipment; and safety issues with handling and disposing of hazardous materials.
- **Improve Secondary Power Systems.** Detailed deficiencies include high failure rates for the jet fuel starter, central gear box, and airframe mounted accessory drives and "antiquated electrical generation and distribution systems."
- **Provide Long Life Maintenance Free Batteries.** Deficiencies in rechargeable battery low mean time between failure (MTBF) are causing unnecessary downtime; weight, volume and hazardous chemical composition of batteries for SOF aircraft and ground forces equipment is a problem; short nonrechargeable battery life for Special Operations Forces are causing personnel to carry multiple spare batteries.
- **Reduce Maintenance / Increase Reliability.** Deficiencies cite low subsystem/component reliability (MTBF); 3-level maintenance support systems with increased pipeline spares requirements and manpower requirements; large maintenance and support costs as technology becomes obsolete in the aging C-5 fleet; and low reliability (MTBF) and maintainability of our fighter forces.
- **Improve Electronic Cooling.** Deficiencies indicate excessive demands on the aircraft during ground operations through overwork of the aircraft's environmental control system that

adversely affects deployability; and electronics cooling inefficiencies that cause lack of cooling for aircrew for pre-mission ground operations.

- **Reduce Hazardous Materials.** Deficiencies cite hazardous materials problems with aircraft/weapon system/support systems associated with hazardous materials where removal, disposal, and replacement impacts safety of operations.

Goals

MEA and advanced concept power technologies are responsive to weapon system needs through technology efforts in each of the subthrust areas of power generation, power distribution, energy storage, and power system integration. Goals for these areas include:

- Demonstrate a lubeless, gearless Internal Starter/Generator to eliminate the airframe mounted accessory drive transmission and its maintenance while increasing electrical power generation reliability by 10-fold.
- Develop and demonstrate the Integrated Power Unit (IPU) to reduce ground equipment by 30-50%, deployment load requirements by 25%, and eliminate potentially carcinogenic hydrazine.
- Develop high voltage electric power distribution and actuation subsystems to reduce and ultimately eliminate dependence on centralized hydraulic systems, resulting in reduced hydraulic system maintenance, fluid disposal, and cleaning fluid logistics and disposal.
- Increase electrical power distribution system fault tolerance by 3-fold (3+ faults), and reliability by 10-fold via high temperature power electronics and utilization of smart, "prioritize/reconfigure," electrical load management centers.
- Increase maintenance free battery life from 2 to 20 years.
- Increase power electronic power density by 20-fold, while utilizing local, passive cooling that minimizes aircraft environmental control system requirements.
- Develop silicon carbide power electronic devices and other high temperature electrical components for a 6X increase in reliable operating temperature (up to 1112° F).

Major accomplishments

Toward advancement in energy storage capability, the Advanced 20-year Maintenance Free Aircraft Battery System (AMFABS) program, designed to eliminate frequent and costly maintenance of vented nickel-cadmium batteries, will be completed this year. System design verification and safety of flight testing is ongoing. AMFABS flight test hardware is scheduled for delivery and integration into the JSTARS aircraft in June 1996. The design flexibility aspects of AMFABS permits application to other aircraft, including F-16, F-117, F-22, and B-52. The sealed nickel-cadmium battery technology developed under the AMFABS program is presently undergoing a flight trial onboard the F-16.

The More Electric Aircraft (MEA) IPU program in performing subsystem testing of the magnetic bearing/rotor support system at up to 80% of design full speed (43,000 rpm). The IPU is a single aircraft power unit that can replace and perform the functions of three separate units: main engine starting, auxiliary power, and emergency power. Application of this unit will result in significant reductions in aerospace ground equipment (AGE). Mechanical checkout of the generator rotor was completed to 55,000 rpm in the subsystem test. Once subsystem tests have been completed, the generator and magnetic bearing will be integrated in an FY96 new start 6.3 program.

As an interim solution to emergency power generation requirements, a series of nontoxic monopropellants are being evaluated as possible replacement propellants for the hydrazine monopropellant used by the F-16 emergency power unit. Hydrazine, a known mutagen and

suspected carcinogen, has received increased visibility as a hazardous material to be eliminated from the logistics tail. During the past year the number of formulations has been reduced to one likely candidate and optimization of the chemical percentages is underway.

The Power Management and Distribution for More Electric Aircraft (MADMEL) program has continued to directly support the F-22 System Program Office (SPO) in terms of advanced, 270-volt power distribution technologies via active F-22 SPO participation in the program activities and direct test/evaluation of F-22 configured components. Critical design has been accomplished, and the program is now in the subsystem fabrication phase.

An alternating current, electrical load management center is currently being transitioned to two aircraft platforms. This technology has been selected to be used on the Advanced Hercules II (C-130J) and by Bombardier Aerospace Group – North America on their long range high speed Global Express business jet. Electrical load management has embedded intelligence that provides fault tolerance and improved reliability for the power system. On the C-130J, this technology enabled the removal of one person (the flight engineer) from the cockpit, resulting in a two-person flight crew. The C-130J rolled out in October 1995, and will go through flight test in February 1996 following extensive ground testing.

Furthering systems integration goals, hardware for the C-141 Electric Starlifter program has been delivered to the 412th Test Wing, Edwards AFB, for modification of the test aircraft. This moves Air Mobility Command closer to retrofitting the hydromechanical actuators of the aileron system with new electronic, integrated actuators packages. This will reduce the cost of maintaining transport aircraft while increasing their reliability and represents a benchmark in the MEA toward electrically-driven subsystems. A 1000-hour, in-service test program will follow initial flight testing and will provide invaluable data on improved maintenance.

In summary, these science and technology programs continue to receive strong endorsements from the Air Combat Command, Air Logistics Centers, numerous SPOs, and other Air Force Materiel Command organizations. In direct response to DoD and Air Force guidance and recommendations from the Scientific Advisory Board (SAB), the aircraft power focus continues to emphasize MEA technologies that take advantage of the greater reliability and performance characteristics offered by electrical and electronic components.

Changes from last year

Based on guidance from a recent DoD review in July 1995, a focus of all MEA programs has shifted toward MEA Generation II identified developments including the integral starter/generator. The external version of the integral starter/generator has successfully transitioned to the Joint Strike Fighter (JSF) initiative's Joint/Integrated Subsystems Technology (J/IST) demonstration. Efforts toward an "internal to the turbine engine" version are now underway with both major turbine engine manufacturers and are managed in both this thrust and the Turbine Engine thrust. In January 1996, the SAB strongly recommended that development and demonstration of the internal starter/generator be accelerated. This technology has been long identified as a cornerstone to the implementation of electrically-based aircraft subsystems and the ultimate capability to eliminate centralized hydraulics.

Silicon Carbide (SiC)-based electronics may have the capability to greatly enhance the high temperature, reliable operation of an MEA. As such, it has been identified as a target technology for Generation II capabilities and has received strong attention from the Defense Advanced Research Projects Agency (DARPA) and from Director of Defense Research and Engineering (DDR&E). In conjunction with Wright Lab's Materials Directorate, DARPA has focused on development of high quality, semiconductor grade SiC material and plans to use this new material for the aggressive development of power electronic devices with our thrust as their

technical lead. The benefits of this technology to military systems are so significant that DDR&E has now established a task force to identify key demonstrations of the insertion of silicone carbide. The task force's recommendations emphasize SiC power electronics for the MEA and other electric conversion development within DoD.

The More Electric Aircraft initiative changed its name during 1995 to the More Electric Initiative with the completion of planning documentation for both Army's electric/hybrid electric tactical ground vehicle and Navy's electric surface ship/submarine programs. The Joint Aeronautical Commanders' group as well as DDR&E are enthusiastic about the synergistic nature of power technologies finding application in a variety of electric conversion activities.

Milestones

Specific milestones contained within the MEA initiative and advanced concepts power include:

- FY96, Delivery of the 500/1000 Amp continuous (4500 Amp rupture), 270-Vdc electromechanical power conductor for integration with starter/generator.
- FY96, Flight test of electrical load management technology on C-130J and the Global Express commercial business jet.
- FY96, Modifications and first flight test of a C-141 with electrically actuated ailerons.
- FY97, Complete inservice evaluation of the C-141 electric aileron actuators.
- FY97, Motor, actuator and breadboard motor drive electronics fabrication, integration and testing for Advanced Motor Controller development.
- FY98, Complete construction of the internal engine starter/generator.
- FY99, Ceramic materials for dielectrics available for high temperature, high power electric current filter applications.
- FY00, Complete engine rig testing of the internal starter/generator.
- FY02, Demonstrate a 100-ampere, 600-V, 572° F silicon carbide switch.

Glossary

AAI	Advanced AMRAAM International
ACC	Air Combat Command
AF	Air Force
AFAE	Air Force Acquisition Executive
AFB	Air Force Base
AFMC	Air Force Materiel Command
AFMPP	Air Force Modernization Planning Process
AFOSR	Air Force Office of Scientific Research
AFSPC	Air Force Space Command
ALCM	Air Launched Cruise Missile
AMC	Air Mobility Command
AMRAAM	Advanced Medium Range Air-to-Air Missile
ANG	Air National Guard
ASC	Aeronautical Systems Center
AST	Advanced Subsonic Technology
ATR	Air-Turborocket
C4I	Command, Control, Communications, Computers, and Intelligence
CRDA	Cooperative Research and Development Agreement
CTC	Center Technology Council
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research & Engineering
DMR	Dual-Mode Ramjet
DoD	Department of Defense
DTAP	Defense Technology Area Plan
DTO	Defense Technology Objective
HiMaTE	High Mach Turbine Engine
HCF	High Cycle Fatigue
HSR	High Speed Research
HySTP	Hypersonic Systems Technology Program
HyTech	Hypersonic Technology
IHPTET	Integrated High Performance Turbine Engine Technology
IPT	Integrated Product Team
IR&D	Independent Research and Development
IRR	Integral Rocket Ramjet
ITALD	Integrated Tactical Air Launched Decoy
JETEC	Joint Expendable Turbine Engine Concept
J/IST	Joint/Integrated Subsystems Technology
JP	Jet Propulsion
JSF	Joint Strike Fighter
JSTAR	Joint Strategic Target & Recognition System
LCC	Life Cycle Cost
LO	Low Observable
MADMEL	Power Management and Distribution for More Electric Aircraft
MAP	Mission Area Plan
MEA	More Electric Aircraft
MEI	More Electric Initiative
NASA	National Aeronautics and Space Administration
NOx	Nitrous Oxides
NWV	New World Vistas
PDE	Pulse Detonation Engine
RAMTIP	Reliability & Maintainability Technology Insertion Program
R&D	Research & Development
RM&S	Reliability, Maintainability, and Supportability
S&T	Science and Technology
SAB	Scientific Advisory Board
SBIR	Small Business Innovation Research
SFC	Specific Fuel Consumption
SOC	Special Operations Command
SOF	Special Operations Forces
SPO	System Program Office
STOVL	Short Takeoff/Vertical Landing
TAP	Technology Area Plan
TDC	Thin Dense Chrome
TEO	Technology Executive Officer
TMI	Third Millennium Initiative
TMP	Technology Master Process
TPIPT	Technical Planning Integrated Product Team
TTO	Technology Transition Office
T/W	Thrust-to-Weight
UAV	Unmanned Air Vehicle
Vdc	Volts Direct Current
VCE	Variable Cycle Engine
VFDR	Variable Flow Ducted Rocket
WL	Wright Laboratory

Technology Master Process Overview

Part of the Air Force Materiel Command (AFMC) mission deals with maintaining technological superiority for the United States Air Force by:

- Discovering and developing leading edge technologies,
- Transitioning mature technologies to system developers and maintainers,
- Inserting fully developed technologies into our weapon systems and supporting infrastructure, and
- Transferring dual-use technologies to improve economic competitiveness.

To ensure this mission is effectively accomplished in a disciplined, structured manner, AFMC has implemented the **Technology Master Process** (TMP).The TMP is AFMC's vehicle for planning and executing an end-to-end technology program on an annual basis.

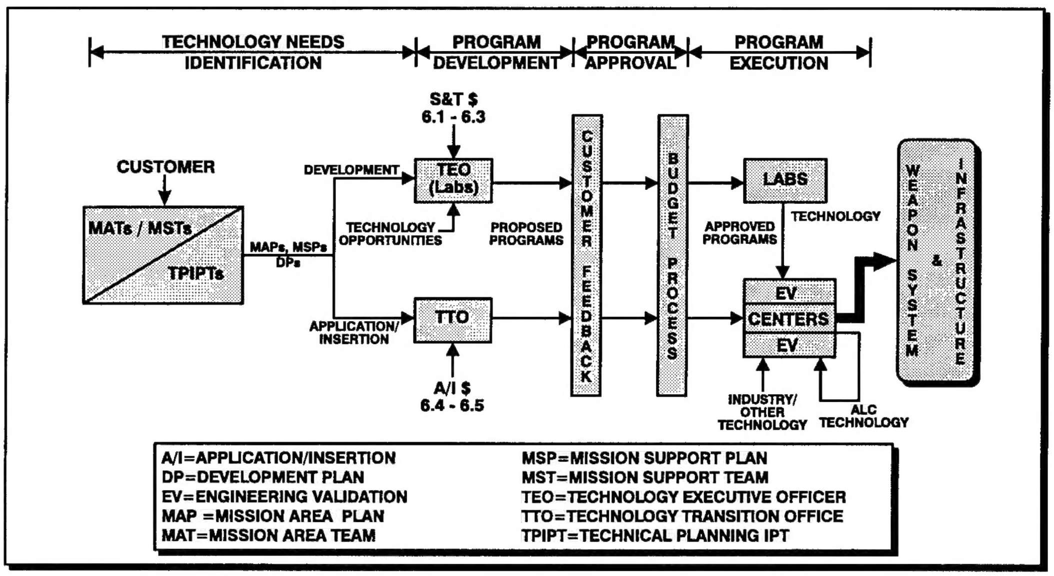

Figure 6.1: Technology Master Process

The TMP has four distinct phases, as shown in Figure 6.1:

- Phase 1, **Technology Needs Identification** – Collects customer-provided and customer-prioritized technology needs associated with weapon systems, product groups, and supporting infrastructure; then identify them by the needs to develop new technology or apply/insert emerging or existing technology. These needs are derived in a strategies-to-task framework via the user-driven Mission Area Planning process.
- Phase 2, **Program Development** – Formulates a portfolio of dollar constrained projects to meet customer-identified needs from Phase 1. The Technology Executive Officer (TEO), with the laboratories, develops a set of projects for those needs requiring development of new technology, while the Technology Transition Office (TTO) orchestrates development of a project portfolio for those needs that can be met by the application/insertion of emerging or existing technology.
- Phase 3, **Program Approval** – Reviews the proposed project portfolio with the customer and obtains approval for the portfolio through the budgeting process. The output of Phase 3 is

the authorization and appropriations required, by the laboratories and application/insertion programs, to execute their technology projects.

- Phase 4, **Program Execution** – Executes the approved S&T program and technology application/insertion program within the constraints of the Congressional budget and budget direction from higher headquarters. The products of Phase 4 are validated technologies that satisfy customer weapon system and infrastructure deficiencies.

Additional information

Additional information on the Technology Master Process is available from HQ AFMC/STR, DSN 787-6777/8764, (513) 257-6777/8764.

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